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Proposal 0138

Rapidity Correlations in pp Collisions at 102 and 400 GeV/c*

C. Bromberg,† T. Ferbel, and P. Slattery
University of Rochester
Rochester, N.Y. 14627

and

A. Seidl and J. C. VanderVelde
University of Michigan
Ann Arbor, Mich. 48104

ABSTRACT

We present a study of two-particle rapidity correlations in inclusive and semi-inclusive reactions in pp collisions at 102 and 400 GeV/c. In particular, we examine the charge, multiplicity and s dependence of these correlations. Our inclusive data provide evidence for the presence of energy independent short-range correlations in rapidity. Significant contributions to these correlations arise from data having high multiplicities. Correlations among particles of like charge are weaker than among particles of opposite charge.

*Research supported by the United States Energy Research and Development Administration.
†Present address: Caltech, Pasadena, Calif. 91125
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I. Introduction

The presence of short-range rapidity correlations among produced pions appears to be a prominent feature of multiparticle production at high energies[1]. Although the energy dependence of these correlations is rather weak, a careful comparison of data from two widely spaced energy points may be of value in determining the type of models which are most relevant for describing multiparticle production at high energies. In this paper we present a study of inclusive and semi-inclusive rapidity correlations in pp collisions at 102 and 400 GeV/c. The data are derived from exposures of the Fermilab 30" bubble chamber to extracted beams of machine energy. The scanning, measuring, and analysis procedures at the two energies were identical, thus providing data samples having a minimum amount of relative systematic bias.[2]

A standard difficulty in the analysis of bubble chamber data at high energies is the unavailability of mass identification for particles with momenta in excess of 1.2 GeV/c in the laboratory frame; below this momentum, estimates of ionization based on bubble density of tracks can be used to separate protons from pions. Because we wish to concentrate our attention on pion-pion correlations, we restrict our analysis to those tracks for which the scaling variable $x = 2p_\ell^*/\sqrt{s}$ has values $x<0.5$. (As usual, s is the square of the energy in the center of mass of the collision, and p_ℓ^* is the longitudinal momentum of a particle in the center of mass, assuming a pion-mass interpretation.) This cut on x, while removing a major percentage of the fast forward-going protons, removes only a small fraction of the forward-produced pions. The additional elimination of those protons that can be identified through ionization yields an inclusive pion-rapidity spectrum which displays approximate symmetry in the pp center of mass, as is required for unpolarized pp collisions. (Our definition of the rapidity variable y is the usual one, namely $y = 1/2 \ln (E+p_\ell)/(E-p_\ell)$, where p_ℓ and E are respectively the longitudinal momentum and energy of the pion.)

In the text we refer to positive tracks as π^+ and to negative tracks as π^- particles. However, we estimate that on the average there exist approximately 1% e^-, 7% K^- and 2% $\bar{p}$ contamination in the negative track sample, and approximately 1% e^+ and 10% K^+ in the sample of positive tracks. Proton contamination is approximately 10-15% in the central region of rapidity, but this increases somewhat at large positive values of y* (starred variables refer to the center of mass system).

II. Inclusive Correlations

We will discuss two-particle rapidity correlations in terms of the normalized correlation function, R, integrated over transverse momenta:

$$R = \frac{\sigma_{inel}\ d^2\sigma/dy_1 dy_2}{d\sigma/dy_1 \cdot d\sigma/dy_2} - 1 ,$$

where σ_{inel} is the total inelastic cross section. In particular, we will present results for the following two-pion inclusive reactions:

$$pp \to \pi^c \pi^c + \text{Anything} \qquad (1)$$

$$pp \to \pi^- \pi^+ + \text{Anything} \qquad (2)$$

$$pp \to \pi^+ \pi^+ + \text{Anything} \qquad (3)$$

$$pp \to \pi^- \pi^- + \text{Anything} \qquad (4)$$

Reaction (1) refers to the production of pions of either charge. The correlation functions for Reactions (1)-(4) will be denoted by R^{cc}, R^{-+},

R^{++}, and R^{--}, respectively.

The full two dimensional structure of rapidity correlations can be best appreciated by examining a plot of contours of constant R-value. We display in Fig. 1 the contours of constant R^{cc} at 102 and 400 GeV/c, obtained by fitting two dimensional polynomials to the R values for Reaction (1). The elongation of the contours about the $y_1^* = y_2^*$ diagonal in the central rapidity region implies that R^{cc} is primarily a function of rapidity separation $y_2^* - y_1^*$. R^{cc} appears to exhibit a much weaker dependence on $y_2^* + y_1^*$.

The structure of these contour plots suggests that the combinations $(Y_2^* - y_1^*)$ and $(y_2^* + y_1^*)$ might be the most economical variables for examining the energy and charge-state dependence of $\pi\pi$ correlations. In Fig. 2 we present the R values for Reactions (1)-(4) using events having rapidity pairs within one unit of the diagonals in Fig. 1. In order to reduce the effects of proton contamination and poor momentum resolution at large positive y*, the data for $y_2^* + y_1^* > 0$ in Figs. 2e-h were obtained by symmetrizing the data for $y_2^* + y_1^* < 0$; similarly π^+ data for $y_2^* > 0$ (Fig. 2b) were obtained by symmetrizing $y_2^* < 0$ data. Figures 2a and 2c contain contributions from positive particles with $y^* > 0$; consequently, these data may be biased because of substantial proton contamination at large y^*.

The strength of the short-range correlation in Reactions (1)-(4) can be assessed by comparing the dependence of R on $(y_2^* - y_1^*)$ and on $(y_2^* + y_1^*)$. This is because it has been shown previously[(3)] that, although the requirement of momentum-energy conservation alone can produce positive values of R in the central region of rapidities, the dependence of R on $(y_2^* - y_1^*)$ and on $(y_2^* + y_1^*)$ is similar for the central region if no dynamic correlations exist in the data. The fitted contours of Fig.1 and the projections in Fig. 2 indicate that R^{cc} falls rapidly with increasing values of $|y_2^* - y_1^*|$ while the peak value of R^{cc} near $(y_2^* - y_1^*) = 0$ changes only slightly for a large range of $(y_2^* + y_1^*)$ values (see, in particular the plateau in R^{cc} in Fig. 2e). An examination of Fig. 2 reveals that the behavior of R in Reaction (1) is influenced largely by the properties of R in Reaction (2). The evidence for a short range component in Reactions (3) and (4) is less significant, in that the data in Figs. 2(c),(d) appear to be only somewhat more peaked at $y_2^*-y_1^*=0$ than the corresponding data for R near $y_2^* + y_1^* = 0$ in Figs. 2(g),(h).

A comparison of the 102 GeV/c and the 400 GeV/c data reveals a very weak energy dependence for the correlation function. In previous investigations of kinematical contributions to these correlations[3], we found that the expected increases in R^{cc} were typically, about 0.02-0.10 units at small $y_2^* - y_1^*$, and about 0.10-0.20 units at large rapidity separations. Because these changes are consistent with our observed variations in R^{cc},we conclude that the dynamics of inclusive short-range correlations have a very weak energy dependence between 102 and 400 GeV/c. This conclusion is supported further in Fig. 3, where the data of Fig. 2e $(y_2^* + y_1^* < 0)$ are shown replotted in terms of laboratory rapidities. The absence of an energy dependence for R at small rapidity separations is a property akin to the scaling of single-particle production spectra observed at these energies.[4]

III. Semi-inclusive Correlations

It has been suggested[5] that examining rapidity correlations in events of fixed multiplicity (semi-inclusive reactions) would provide additional insights into the origin of short range correlations. Data on semi-inclusive correlations at high energies have been presented in the past;[6] we will here summarize the results of our investigations.

In analogy with expression for R, we define the semi-inclusive function:

$$R_n = \frac{\sigma_n \, d^2\sigma_n/dy_1 dy_2}{d\sigma_n/dy_1 \; d\sigma_n/dy_2} - 1$$

where n represents the topological channel or the charged-particle multiplicity, and the σ_n are the semi-inclusive (n-prong) cross sections. The correlation functions for Reactions (1)-(4) are given in Figs. (4)-(11). Again, in analogy with the fully inclusive correlation functions, we have defined R_n^{cc}, R_n^{-+}, R_n^{++} and R_n^{--}, and the following:

$$R_n'^{cc} = R_n^{cc} + 1/n$$

$$R_n'^{-+} = R_n^{-+}$$

$$R_n'^{++} = R_n^{++} + 1/n_+$$

$$R_n'^{--} = R_n^{--} + 1/n_-$$

where n_+ and n_- are respectively the number of positive and negative particles for any specific topology ($n=n_+ + n_-$). These factors offset the corresponding R_n such that $R_n'=0$ implies a lack of correlation. (We note, however, that although the requirement of energy-momentum conservation for events of fixed multiplicity introduces departures from $R_n'=0$, such departures are small and, unlike those for the fully inclusive functions, are essentially independent of beam momentum.) The data in Figs. (4)-(11) have been treated in the same manner as the data used in the inclusive analysis.

There is clear evidence for a short-range correlation (near $y_2^* - y_1^* \sim 0$) for data from Reactions (1) and (2). At 102 GeV/c a peak in R_n is evident for multiplicities through n=10, while in the 400 GeV/c an enhancement is observed up to n=14 (Figs. 4-7). These multiplicities are well above those in which diffractive events could contribute significantly to the observed correlations. However, we note that for several lower multiplicities, particularly for n=6 at 102 GeV/c and n=8 at 400 GeV/c, the magnitude of the correlation function for small rapidity separations is smaller at $|y_2^* + y_1^*| = 0$ than at $|y_2^* + y_1^*| \gtrsim 2$. The absence of a plateau in the correlation function for these particular cases might be due to the presence of simultaneous contributions from diffractive and non-diffractive events to these multiplicities.

For each multiplicity the short range structure is more pronounced in the 400 GeV/c data than in the data at 102 GeV/c. The values of $R_n'^{cc}$ and $R_n'^{-+}$ at $|y_2^* - y_1^*| = 0$ in every case are larger at the higher energy. In cluster models[5] this is interpreted as the result of an increase in the rapidity separation between individual clusters at 400 GeV/c. In contrast to the magnitude of R_n', the extent of the short-range structure in rapidity space does not seem to be strongly dependent on either the multiplicity or the incident momentum.

Data from Reactions (3) and (4) are shown in Figs. (8)-(11). Although our results appear to support the presence of structure near $y_2^* - y_1^* = 0$, our statistics are limited, and we can only state that correlations in the ++ and -- semi-inclusive channels are $\lesssim$ 30% of those found in +- data.

IV. Conclusions

We have demonstrated the existence of short range rapidity correlations for inclusive and semi-inclusive two-pion-reactions in pp collisions at 102 and 400 GeV/c. These short range effects are dominated by correlations between π^+ and π^- mesons. Only weak evidence for similar correlations exist for pions of like charge. The energy dependence of inclusive correlations is weak and can be attributed largely to non-dynamic effects. Semi-inclusive correlation data indicate that short range behavior is present in multiplicities well above the mean multiplicity, both at 102 GeV/c and at 400 GeV/c. At fixed multiplicity, short range effects in the correlation function are more prominent in the higher energy data; however the range of correlation in rapidity does not seem to be multiplicity or momentum dependent.

We thank D. Chaney and for help with the analysis and D. Cohen for his contributions in the early phases of this experiment.

Footnotes and References

1. J. Whitmore, Phys. Reports 10 (1974) 273; T. Ferbel, in Proceedings of the 1974 SLAC Summer Institute on Particle Physics, ed. by M. Zipf; L. Foa, Phys. Reports, 22c (1975) 1; P. Darriulat, paper given at the XVIth International Colloquium on Multiparticle Reactions, Oxford, England (1975).

2. For a description of the data analysis see C. Bromberg, Ph.D. Thesis (1974) University of Rochester (unpublished).

3. The multiplicity distribution and the nature of the semi-inclusive rapidity spectra produce positive R values in the central regions of y^*. See C. Bromberg et al., Phys. Rev. D9 (1974) 1864 and D10 (1974) 3100 for a discussion of these effects at 102 GeV/c.

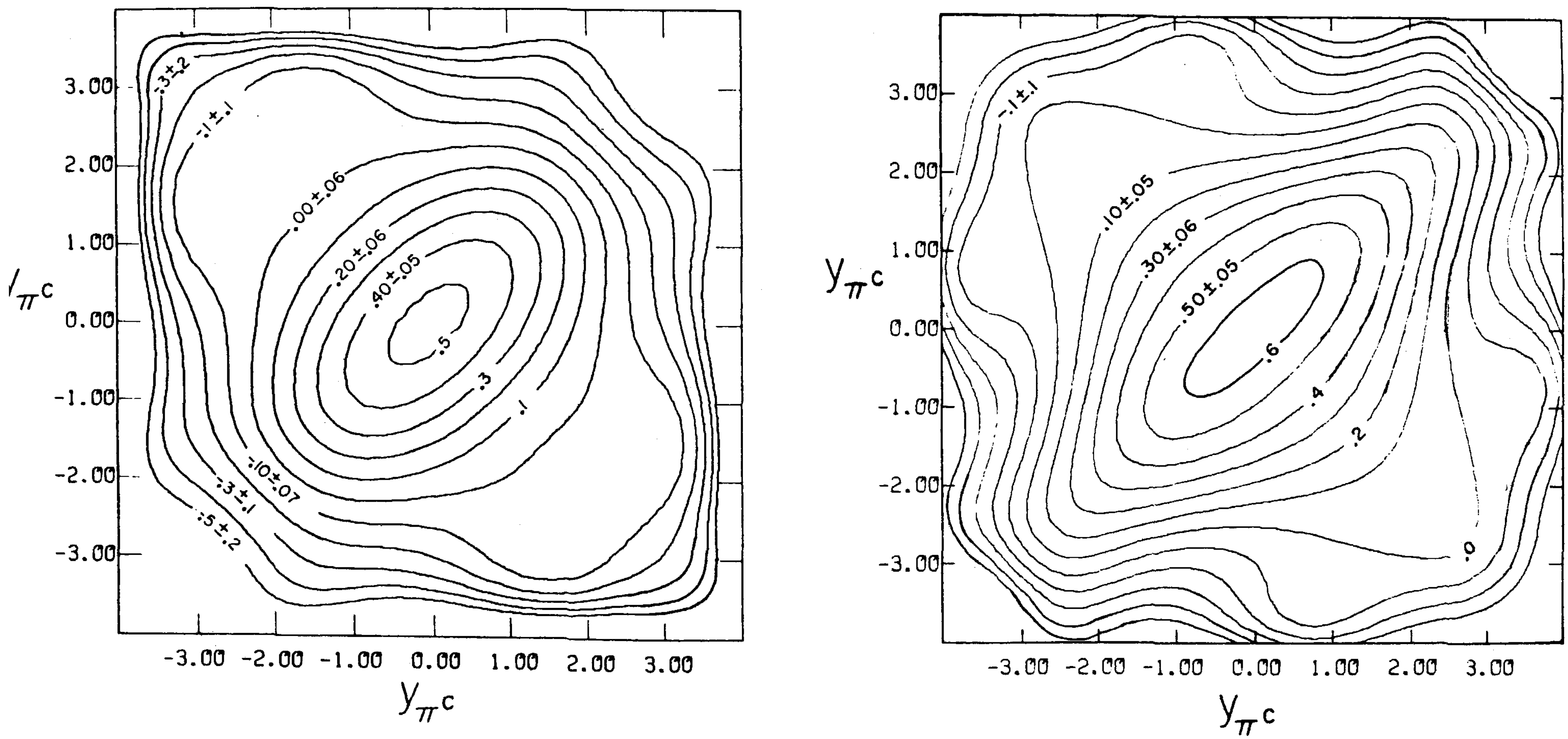
4. C. Bromberg et al., Nucl. Phys. B107 (1976) 82.

5. W.Ko, Phys. Rev. Letters 28, 935 (1972); E.L.Berger, Phys. Letters, 49B (1974) 369; J.Ranft and G. Ranft, Nucl.Phys. B83 (1974) 285.

6. R. Singer et al., Phys. Letters 49B (1974).481; B. Y. Oh et al., Phys. Letters 56B (1975) 400; K. Eggert et al.,Nucl. Phys. B86 (1975) 201; S. R. Ammendolia et al., Nuovo Cimento 31 (1976) 17.

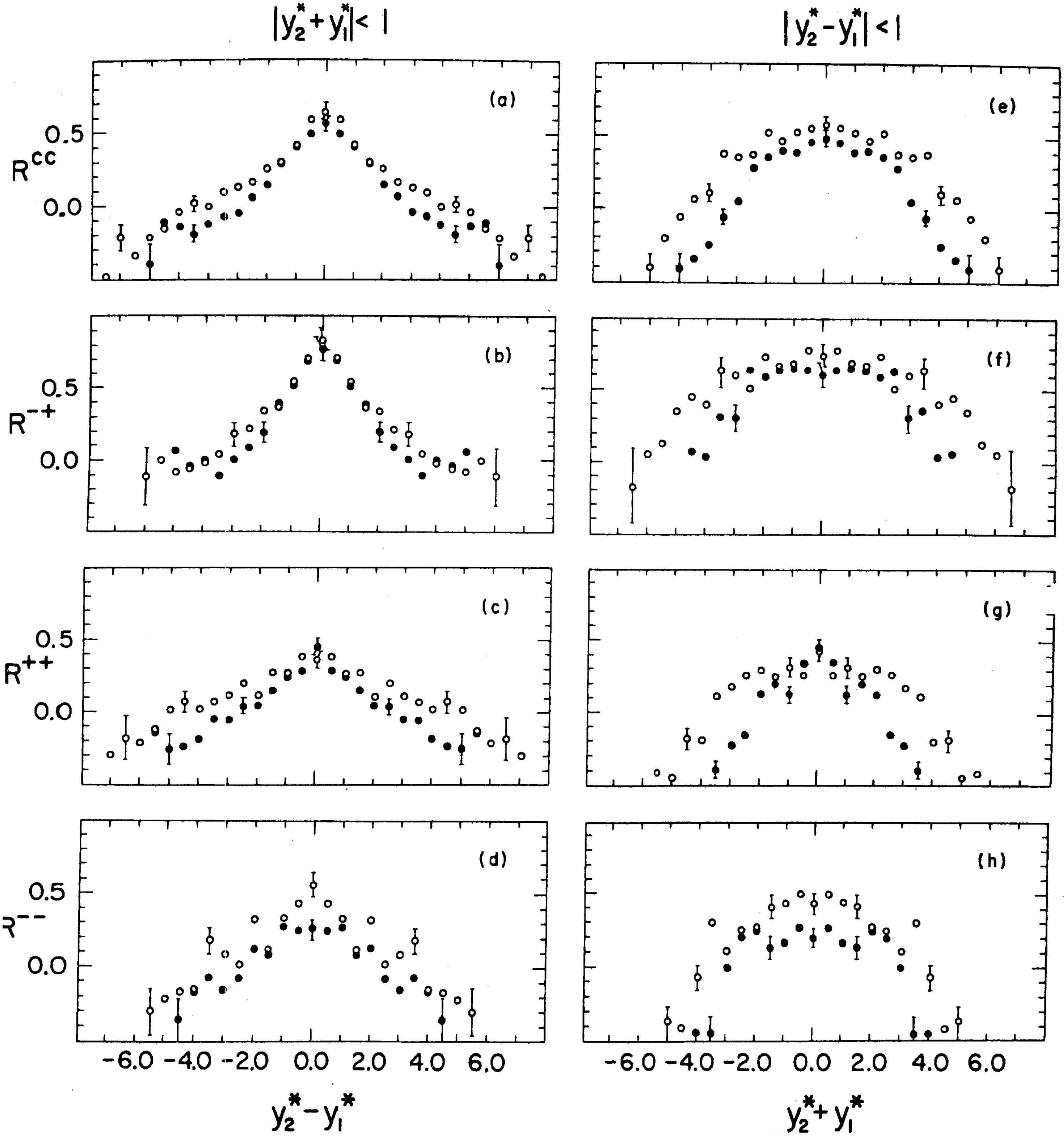
Figure Captions

1. Fitted contours of constant value of the correlation function R for Reaction (1) at 102 GeV/c and 400 GeV/c.
2. Values of the correlation function R in Reactions (1)-(4); particle rapidities are restricted to $|y_2^* + y_1^*| < 1$ in (a)-(d), and to $|y_2^* - y_1^*| < 1$ in (e)-(h). Solid points are for 102 GeV/c, circles for 400 GeV/c data.
3. The correlation function R for Reaction (1) expressed in terms of laboratory rapidities; rapidities are restricted to $|y_2 - y_1| < 1$. Solid points are for 102 GeV/c, circles are for 400 GeV/c data.
4. Values of the correlation R_n' for Reaction (1) at 102 GeV/c.
5. Values of the correlation R_n' for Reaction (1) at 400 GeV/c.
6. Values of the correlation R_n' for Reaction (2) at 102 GeV/c.
7. Values of the correlation R_n' for Reaction (2) at 400 GeV/c.
8. Values of the correlation R_n' for Reaction (3) at 102 GeV/c.
9. Values of the correlation R_n' for Reaction (3) at 400 GeV/c.
10. Values of the correlation R_n' for Reaction (4) at 102 GeV/c.
11. Values of the correlation R_n' for Reaction (4) at 400 GeV/c.



-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
$y_{\pi}c$
.5
.3
.1
.40±.05
.20±.06
.00±.06
-.1±.1
-.3±.2
-.10±.07
-.3±.1
-.5±.2
.6
.4
.2
.0
.50±.05
.30±.06
.10±.05
-.1±.1

Fig 1



$|y_2^* + y_1^*| < 1$
$|y_2^* - y_1^*| < 1$
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
R^{cc}
R^{-+}
R^{++}
R^{--}
0.5
0.0
-6.0 -4.0 -2.0 0.0 2.0 4.0 6.0
$y_2^* - y_1^*$
$y_2^* + y_1^*$

Fig 2

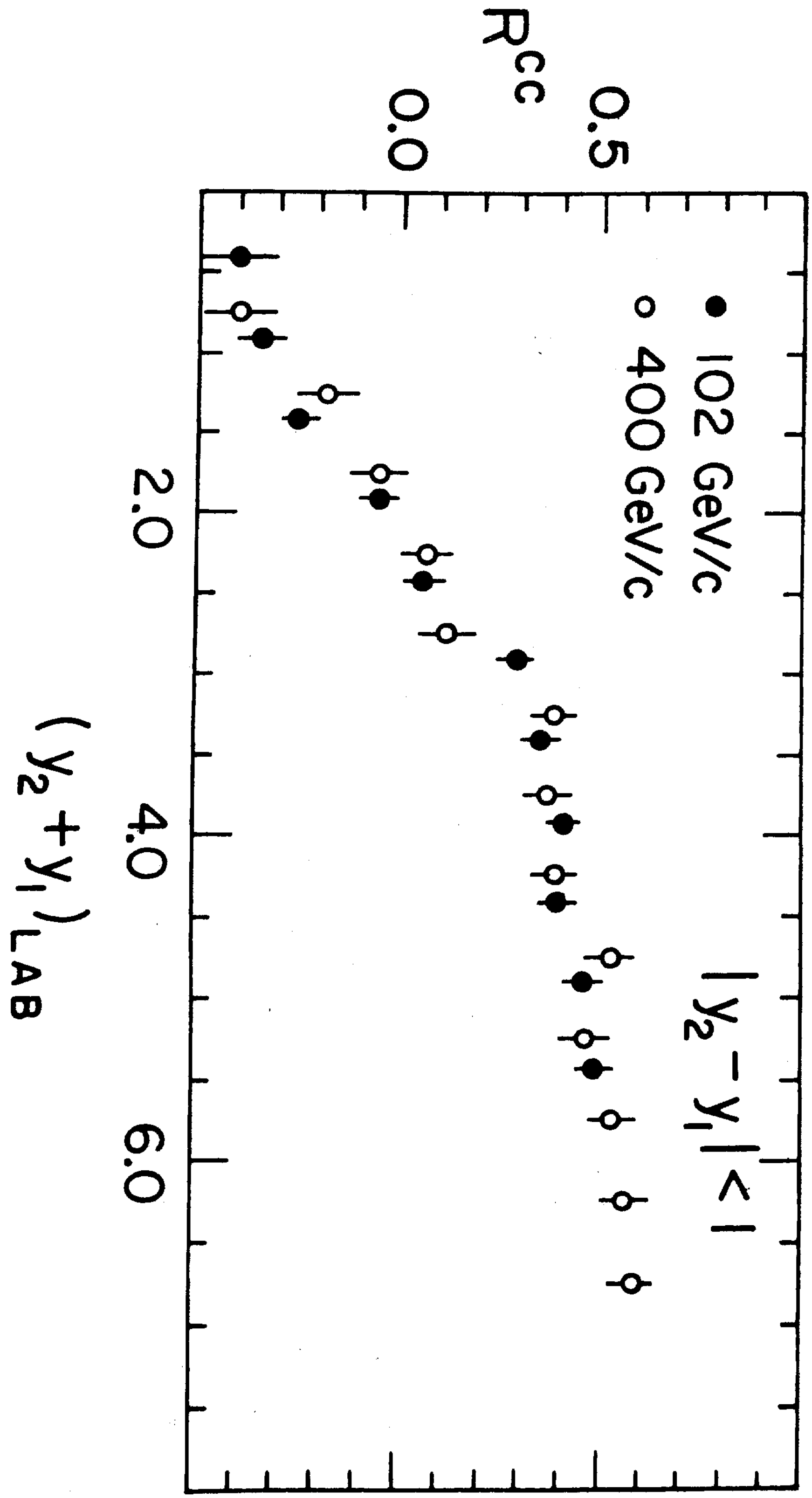


Figure 3

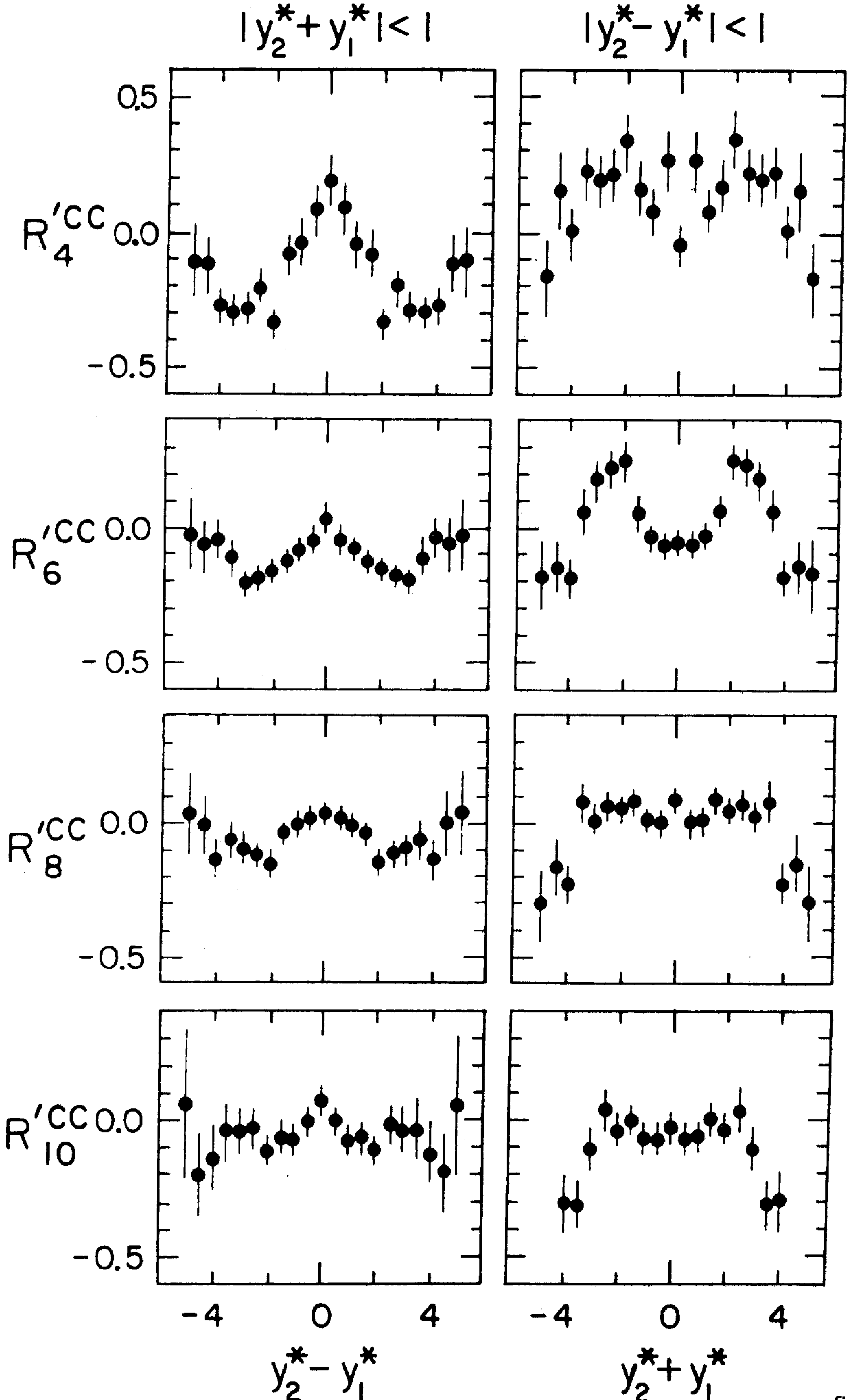
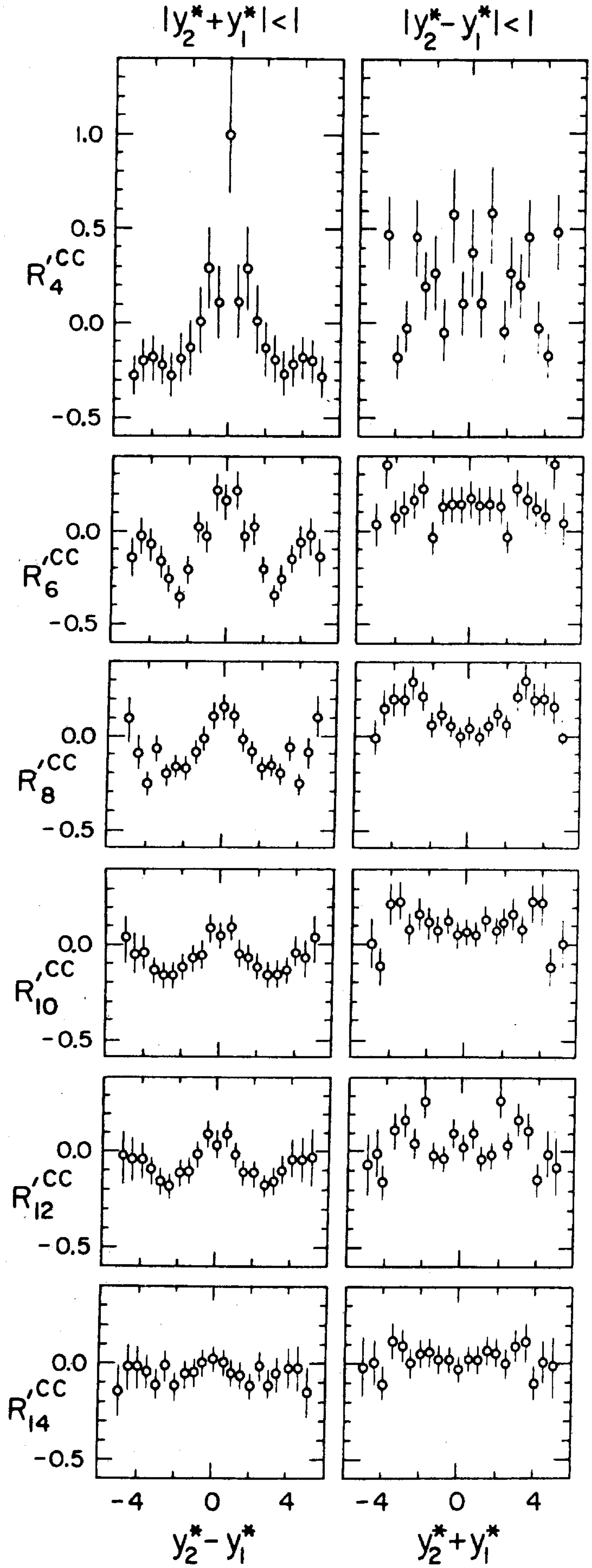
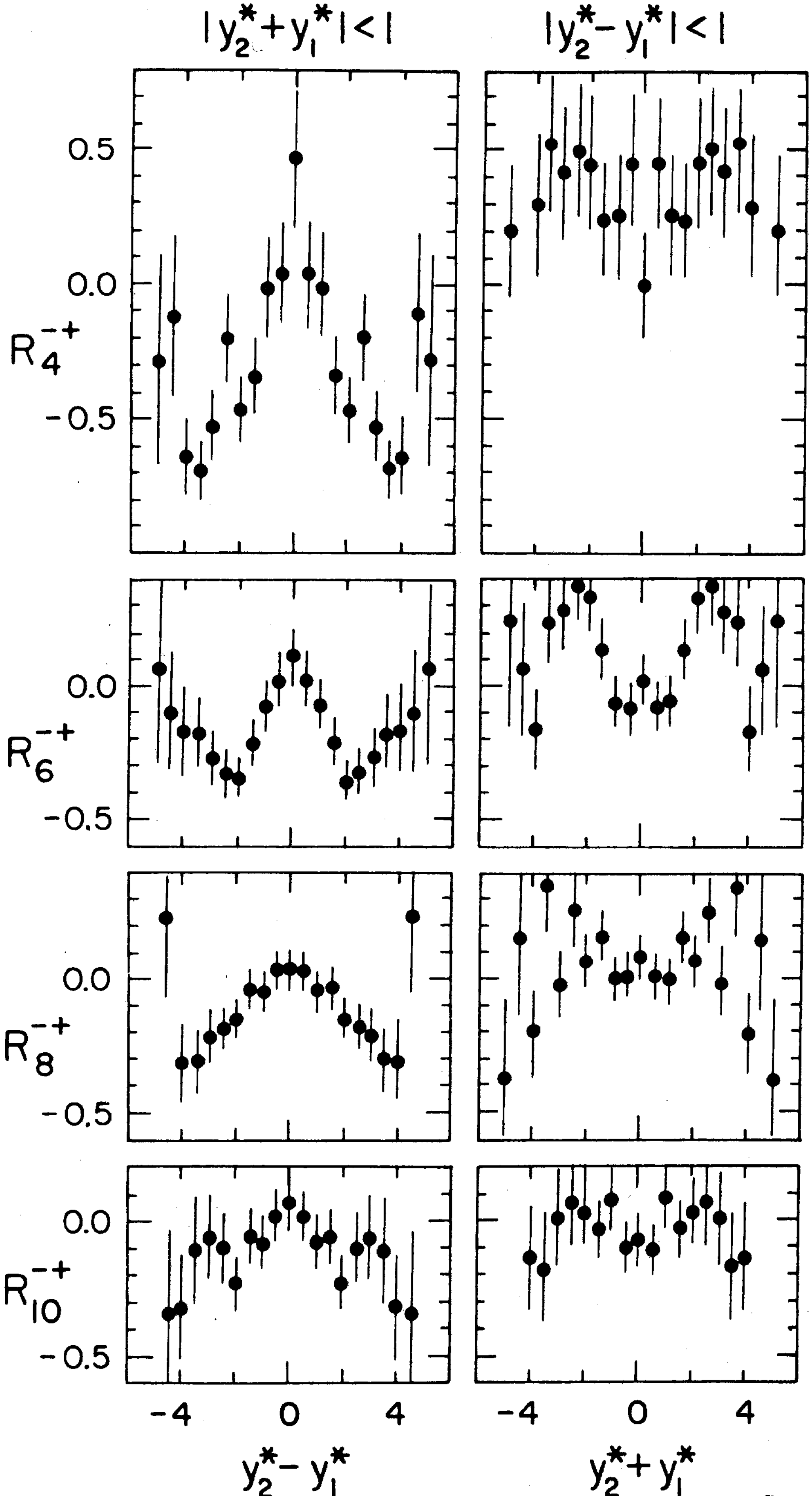


figure 4



$|y_2^*+y_1^*|<1$
$|y_2^*-y_1^*|<1$
1.0
0.5
0.0
-0.5
$R_4'^{cc}$
$R_6'^{cc}$
$R_8'^{cc}$
$R_{10}'^{cc}$
$R_{12}'^{cc}$
$R_{14}'^{cc}$
-4
0
4
$y_2^*-y_1^*$
$y_2^*+y_1^*$

figure 5



$|y_2^* + y_1^*| < 1$
$|y_2^* - y_1^*| < 1$
0.5
0.0
R_4^{-+}
−0.5
0.0
R_6^{-+}
−0.5
0.0
R_8^{-+}
−0.5
0.0
R_{10}^{-+}
−0.5
−4
0
4
−4
0
4
$y_2^* - y_1^*$
$y_2^* + y_1^*$

figure 6

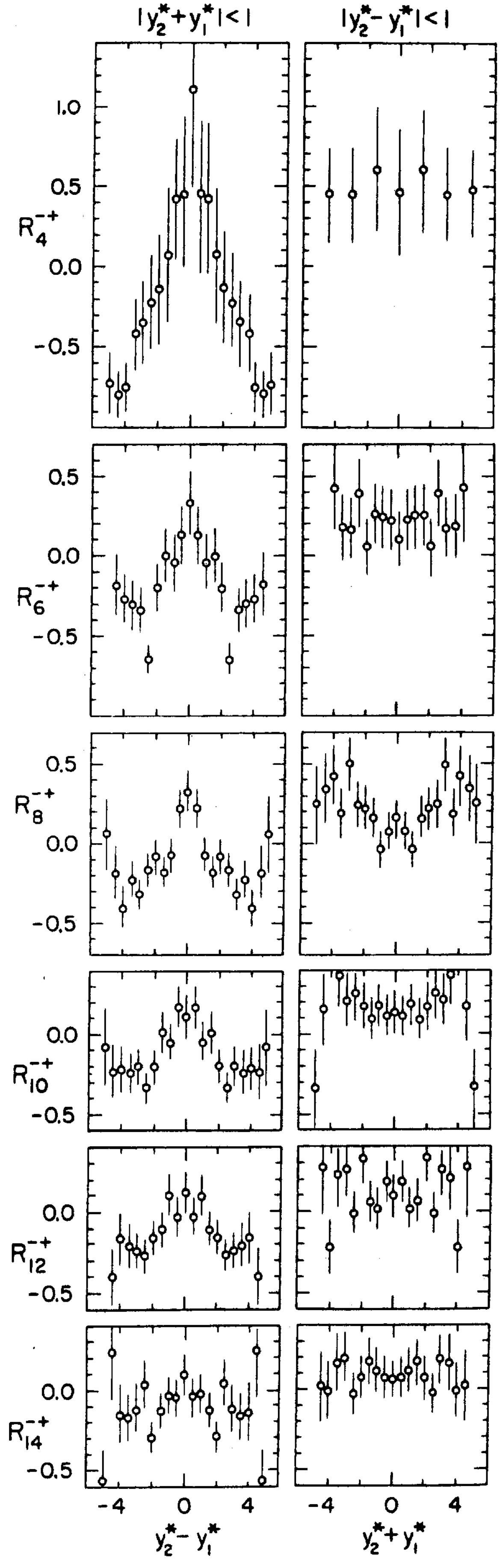


figure 7

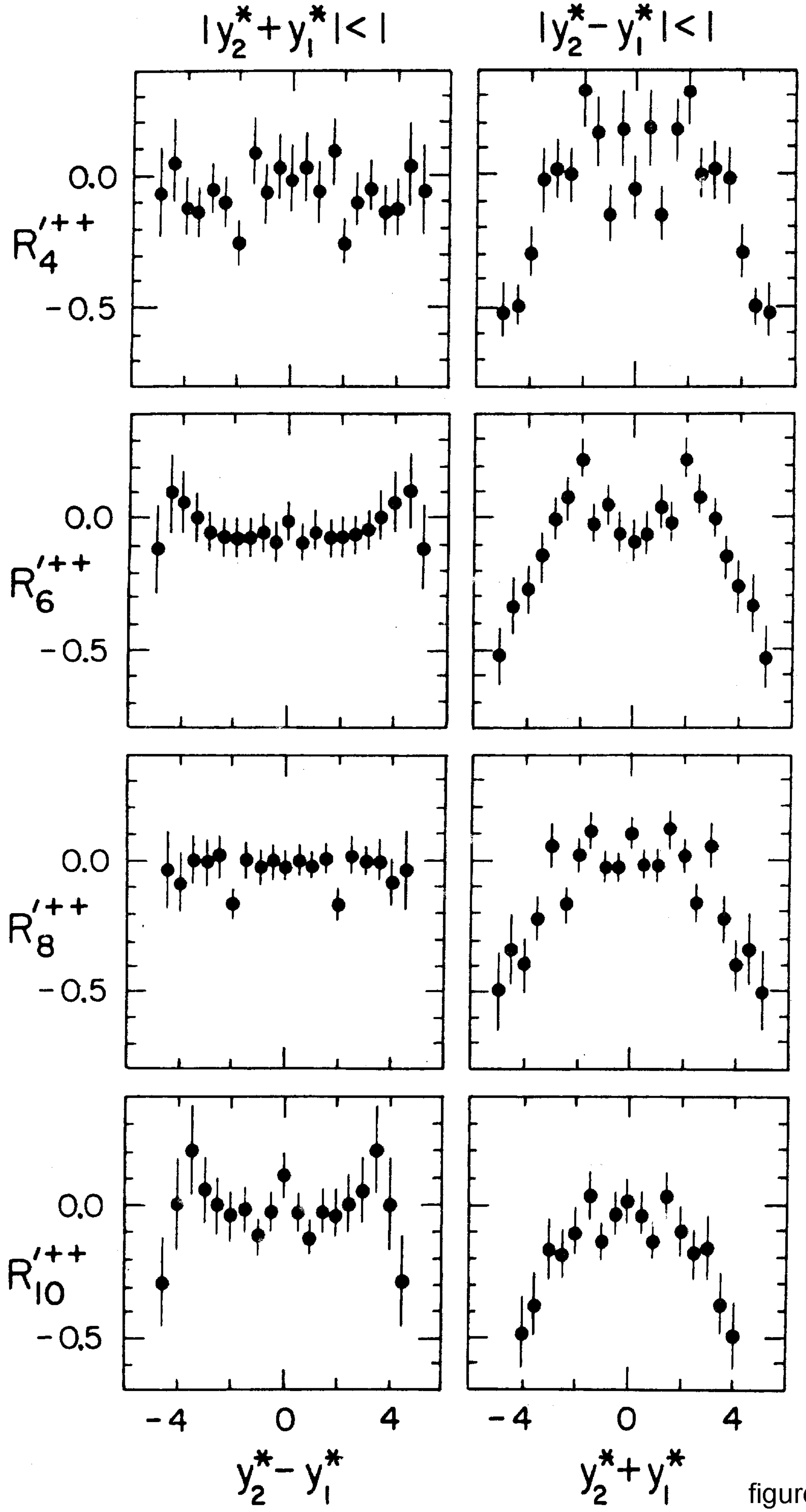


figure 8

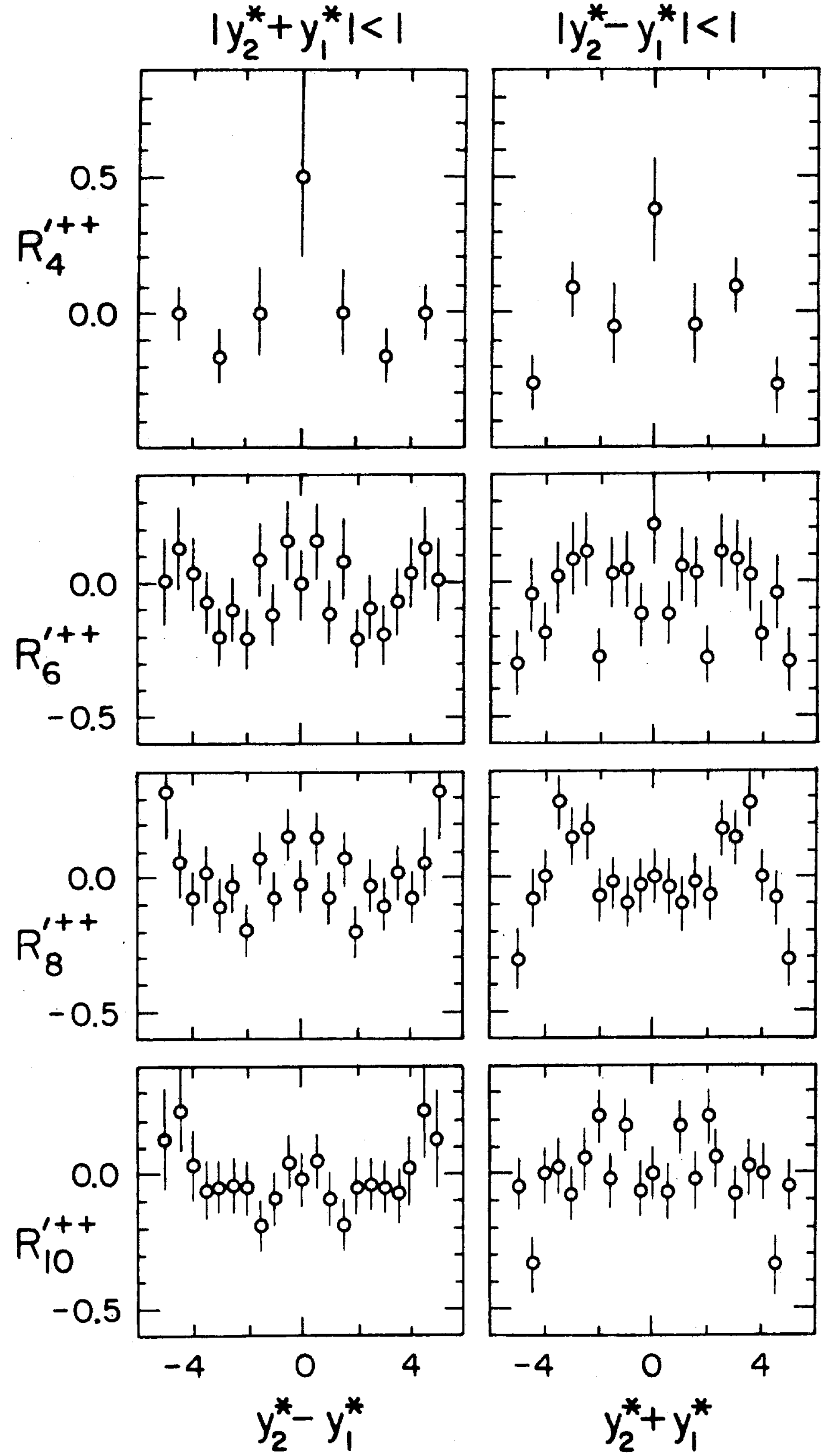


figure 9

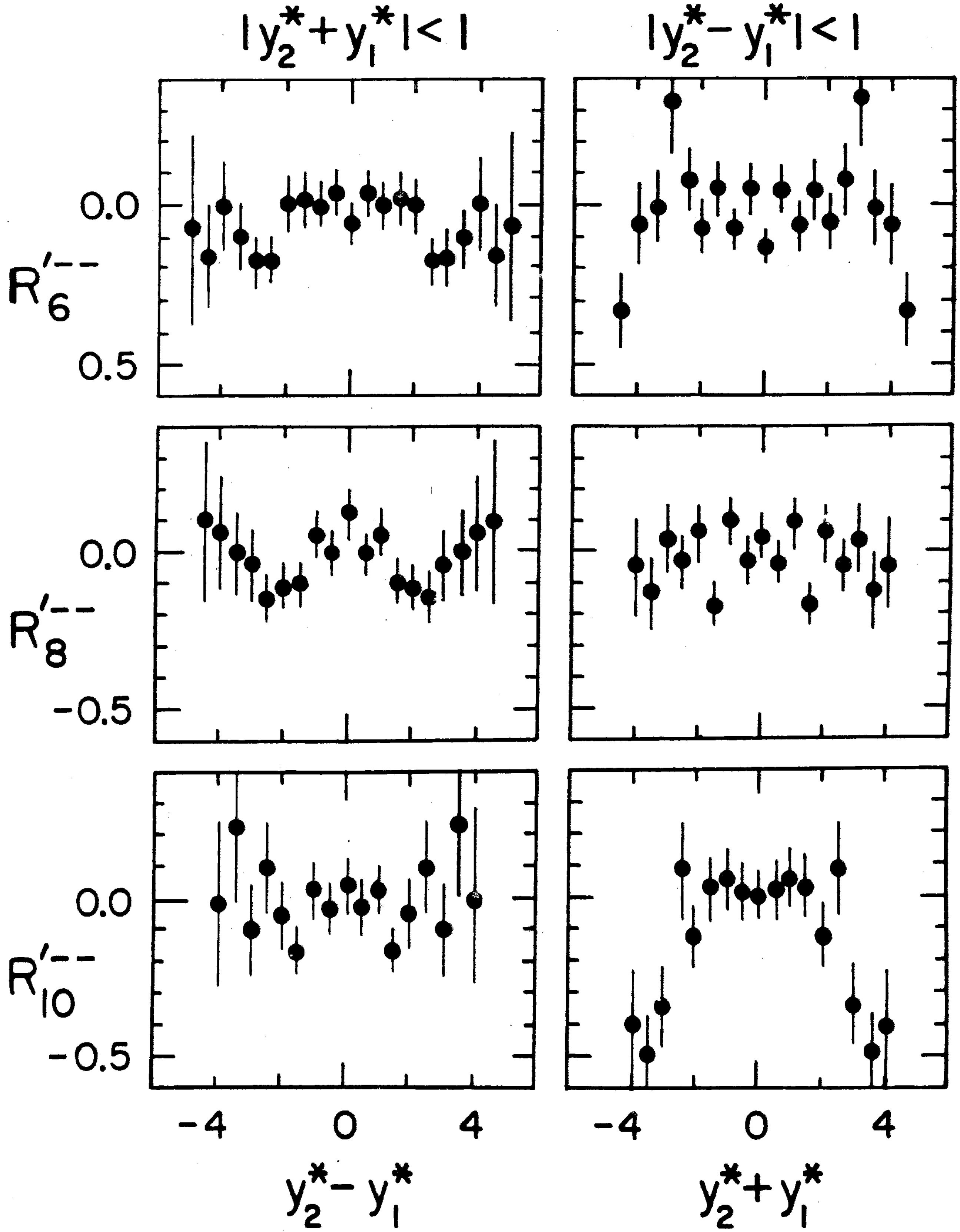


figure 10

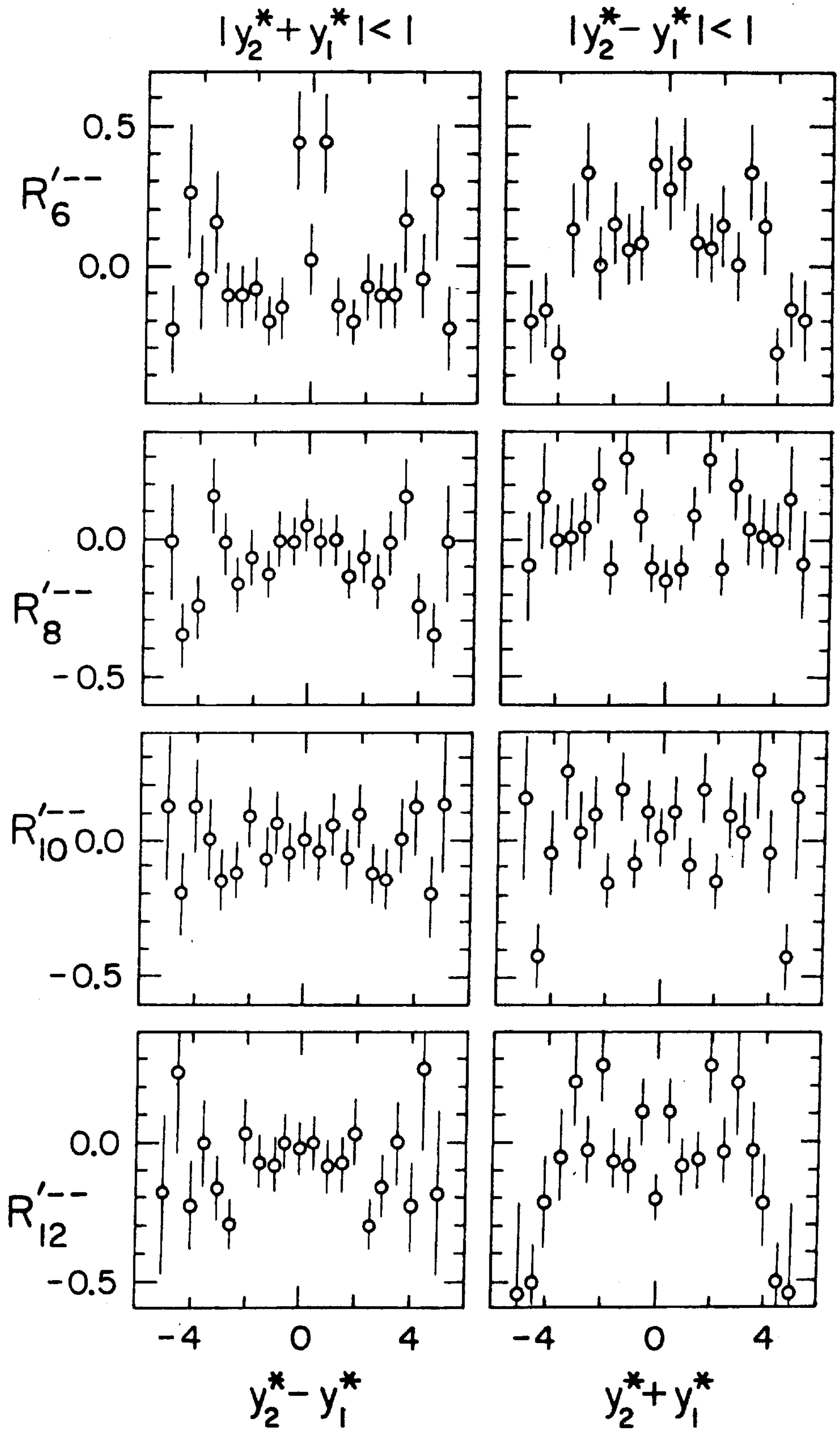


figure 11

Date : 10/16/73

Experiment 138 II

has become Experiment 138 ?

Experiment 138 I

has become Experiment 252